DEPARTMENT OF

CIVIL ENGINEERING

Laboratory Report on the Preparation of STEEL REINFORCED SPECIMENS INCORPORATING PORTLAND CEMENT / FLYASH / SLAG / SILICA FUME FOR DURABILITY STUDIES IN THE MARINE ENVIRONMENT

CANMET
ENERGY, MINES AND RESOURCES CANADA

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PHASE VII

for the

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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Laboratory Report

1. Introduction

The Department of Civil Engineering of the University of New Brunswick was awarded contracts in 1978, 1979, 1980, 1981, 1982 1985, and 1987 by the Department of Supply and Services to prepare large concrete specimens for use by the Department of Energy, Mines and Resources (EMR) in durability studies at the U.S. Corps of Engineers salt water exposure site at Treat Island, Maine. Copies of the corresponding laboratory reports can be obtained from EMR in Ottawa. The first two reports cover specimens containing Type 10 and Type 50 cement with varying percentages of cement replacement with slag and fly ash and with aggregate from the Blagdon Pit. The first report also includes the use of high range water-reducers. The third report covers the use of slag as a replacement for Type 10 and Type 50 cements in semi- lightweight concrete made from expanded shale aggregates. The fourth report covers the use of Type 10 and Type 50 cement in concrete made from sand from the Blagdon Pit and limestone coarse aggregate from the Brookville Pit. The fifth report covers the use of slag and silica fume both as a replacement and as an additive to the normal Portland cement. The sixth report covers the use of steel fibers, fly ash and silica fume as an additive for Type 20 Portland cement when used with low density aggregates made from expanded shale. This, the seventh report relates the preparation of steel reinforced

concrete prisms with varying amounts of cover incorporating type 10 Portland Cement in combination with blast furnace slag, silica fume or fly ash.

The work statement for this contract with associated amendments is given in Appendix A.

The Canadian Standards Association Standard CAN3-A23.1-M77 on "Concrete Materials and Methods of Concrete Construction" and CAN3-A23.2-M77, "Methods of Test for Concrete" were followed, unless otherwise noted.

2. Materials

(a) Cement

Type 10 cement was supplied by Canada Cement Lafarge Ltd. and was delivered in paper bags. All cement was free of lumps and was free flowing. The chemical analysis of the cement, produced at their Brookfield, Nova Scotia plant, is included in Table I.

(b) Slag

The blast furnace slag was supplied by Standard Slag Cement and was delivered in steel drums. A typical analysis of the material is given in Table I.

(c) Fly Ash

The fly ash was supplied by L.E. Shaw from their Lingan, N.S. plant. This bituminous fly ash was supplied in a plastic drum, was free of lumps and was free flowing. A copy of a typical analysis for this fly ash is included in Table I.

(d) Silica Fume

The silica fume was supplied by SKW Canada Inc. from their Bécancour plant in Quebec and was delivered in metal drums. The silica fume was free of lumps and was free flowing. A typical analysis of this silica fume is included in Table I.

(e) Air Entraining Agent

The air entraining agent was a sulphonated hydrocarbon type AEA supplied by W.R. Grace.

(f) Superplasticizer

The superplasticizer was a napthalene-based superplasticizer supplied by Arrow Construction Products and was manufactured by ICI Americas Inc. of Wilmington, Delaware. It was delivered in a 5 gallon metal container.

(g) Aggregates

The fine and coarse aggregates were obtained from the Blagdon Pit. Results of tests carried out on the aggregate are given in Table I.

(h) Reinforcing Steel

Reinforcing bar of 10 and 20 mm diameter was supplied locally by York Structural Steel. All steel was of grade 400 stock. .

3. Preparation and Placement of Reinforcing Cages

Three reinforcing cages of different sizes were fabricated for each prism. For each mix design two prisms were cast providing cover of 20/40/60 mm and 30/50/70 mm, respectively. The design of the cages is shown in Appendix B. Each cage consisted of 3 stirrups of 10 mm diameters bent to form a square of the appropriate dimension. The stirrups were secured by form wire to 4 lengths of 20 mm rebar. Care was taken to ensure that the dimension of the finished cage was within 1 mm of specification.

Prior to mixing the cages were placed in the form using specially designed racks. The rack held the cages the specified distance from the bottom of the form. Wooden spacers were used to prevent lateral movement of the cages while they were secured with monofilament line. After the cages were in place the spacers were removed and correct positioning verified by a series of measurements on each cage. A tables of all measurements are given in Appendix B. Photographs of reinforcing cages installed in the forms are presented in Appencix B.

4. Batching and Mixing

To facilitate handling of the various ingredients and to enable adjustments to be made to the mix, the ingredients were batched in two lots of equal size. The fine and coarse aggregates, cement, and slag were weighed out in plastic buckets and the fly ash and silica fume were weighed out in plastic bags.

The mixer was started and one half the fine aggregates, one half the coarse aggregates, one half the cements, in that order, were dumped by hand into the mixer. Immediately prior to charging the mixer one half of the air- entraining admixture was added to one litre of water and stirred. Once half the cements were in the mixer, one half the water was added followed by the addition of the air entraining admixture.

Air content by the pressure method and slump were determined after 5 minutes of continuous mixing. Any changes that needed to be made were incorporated into the second half of the mix. The balance of the constituents of the mix were added in the same manner as the first half and mixed for an additional 5 minutes. The mix descriptions are given in Table II. When mixing was completed, the concrete was discharged into a wheelbarrow and remixed with a shovel.

Specimens were cast in two layers of equal thickness and consolidated by vibration after each addition of concrete. Hand scoops were used in placing the concrete and care was taken not to disturb the reinforcing cage. The cylinders and large prisms were consolidated using a poker-type vibrator.

5. Testing of the Plastic Concrete

Prior to casting, the concrete was tested for air content by the pressure method, slump and unit weight. The concrete was consolidated using a vibrating table. The temperature of the concrete was measured using a steel jacketed thermometer. The properties of the plastic concrete can be found in Table III.

6. Testing of the Hardened Concrete

The unit weight of the 150 ϕ x 300 mm cylinders weas measured at one day and is recorded in Table IV. Using the unit weight of the concrete and the batch proportions, the mix proportions per cubic meter were calculated and are recorded in Table V. The weights of the fine and coarse aggregates are given in a saturated surface-dry condition.

The compressive strengths at 28 and 91 days are recorded in Table VI. Table VII lists the modulus of elasticity of the concrete as determined by ASTM 649 at 28 days.

When all the specimens had been cured for 91 days, the prisms and cylinders were removed from the moist curing room. Compressive strength of two cylinders from each batch was determined. The prisms were tested in the lab for resonant frequency and ultrasonic pulse velocity in both the wet and dry condition

7. Conclusions

On November 24, 1987 after 91 days of moist curing the concrete prisms were transported to Treat Island snd installed on the wharf at mid tide level.

APPENDIX A

APPENDIX "A"

WORK STATEMENT:

The work is part of a project aimed at developing long-term performance data for concrete exposed to sea waters. Performance is evaluated through field testing of large concrete specimens at the exposure site of Treat Island, Me.

This phase will include the making in the laboratory of eight (8) air-entrained concrete mixes with a water to cementitious materials ratio of 0.5 as follows:

Mix No. 1. Control - 100% Type 10 Portland Cement (PC)
2. Same as Mix No. 1
3. 75% Type 10 P.C. and 25% Fly Ash (FA)
4. Same as Mix No. 3
5. 90% Type 10 PC and 10% Silica Fume (SF)
6. Same as Mix No. 7
7. 50% Type 10 PC and 50% Slag
8. Same as Mix No. 11

The above will use the following:

Cement Type 10 from Maritimes
Fly Ash from Lingan N.S. Plant
Silica Fume from Becancour, Quebec
Ground Pelletized Slag from Hamilton, Ontario

The fine and coarse aggregate shall be from Blagdon, N.B. The coarse aggregate will be 20 mm maximum size. The air entraining agent shall be a sulphonated hydrocarbon type and shall be added so as to produce 6.5±0.5% air. A sulphonated naththalene condensate type superplasticizer (i.e. Mighty 150) shall be used to compensate for any loss of slump due to the use of silica fume. Mixes shall be prepared in a laboratory pan type mixer of 0.12 m^3 minimum capacity to accommodate for the test specimen requirements of each mix.

From each of the eight (8) mixes, one 305 x 305 x 915-mm prism and four 152 x 305-mm cylinders shall be cast. A series of three reinforcing steel cages shall be placed in each prism. For the odd numbered mix prisms, these cages shall be positioned such as to provide for concrete covers of 10, 30 and 50 mm on the sides and bottoms of the prisms. For the even numbered mix prisms, positioning of the three cages shall be such as to provide for concrete covers of 20, 40 and 60 mm on the sides and bottoms of the specimens. Each cage will be securely anchored in the form, and cages with different amounts of cover will be separated by 60 mm from each other and 100 mm from each end of the prism. Cover of all reinforcing will be 80 mm on the top surface. Cages shall be suspended in the frame in a manner so as to prevent electrical contact between cages.

Before casting, properties of the fresh concrete such as temperature, slump, unit weight, and air content shall be determined. Density of the hardened concrete shall be taken on the cylinders at one day or upon removing from the molds. All specimens including the large prisms shall be stored under moist-curing conditions until being tested or shipped to the exposure site.

At 28 days, two cylinder specimens from each mix shall be tested in compression, and for modulus of elasticity. The remaining two cylinders from each mix shall be tested in compression at the age of 90 days. All prisms shall be shipped to the exposure site (Treat Island) after a minimum of 90 days of moist curing. Initial pulse velocity and resonant frequency readings shall be taken on each prism after removal from curing room using procedures. The contractor shall make all necessary arrangements to insure safe delivery and proper installation of the specimens at the exposure site.

CANMET Mix No.	Size	Specimen Number	Age Days	Remarks
1	305x305x915	Z01		91 days moist + air dry
	150ϕx300	Z01-1	28	Mod. of E and compression
		-2	28	Mod. of E and compression
		-3	91	Compression
		-4	91	Compression
2	305x305x915	Z02		91 days moist + air dry
	150ϕx300	Z02-1	28	Mod. of E and compression
		-2	28	Mod. of E and compression
		-3	91	Compression
		-4	91	Compression
3	305x305x915	Z03		91 days moist + air dry
	150ϕx300	Z03-1	28	Mod. of E and compression
		-2	28	Mod. of E and compression
		-3	91	Compression
		-4	91	Compression
4	305x305x915	Z04		91 days moist + air dry
	150ϕx300	Z04-1	28	Mod. of E and compression
		-2	28	Mod. of E and compression
		-3	91	Compression
		-4	91	Compression
5	305x305x915	Z05		91 days moist + air dry
	150ϕx300	Z05-1	28	Mod. of E and compression
		-2	28	Mod. of E and compression
		-3	91	Compression
		-4	91	Compression
6	305x305x915	Z06		91 days moist + air dry
	150ϕx300	Z06-1	28	Mod. of E and compression
		-2	28	Mod. of E and compression
		-3	91	Compression
		-4	91	Compression
7	305x305x915	Z07		91 days moist + air dry
	150ϕx300	Z07-1	28	Mod. of E and compression
		-2	28	Mod. of E and compression
		-3	91	Compression
		-4	91	Compression
8	305x305x915	Z08		91 days moist + air dry
	150ϕx300	Z08-1	28	Mod. of E and compression
		-2	28	Mod. of E and compression
		-3	91	Compression
		-4	91	Compression

1987 CANMET CONTRACT

SERIES	in % Cement	Fly Ash	Silica Fume	Slag	Cover mm	Notation of Casting CANMET	Date
Z 01	100	0	0	0	30/50/70	1	87 08 14
2	100	0	0	0	20/40/60	2	87 08 14
3	75	25	0	0	30/50/70	3	87 08 18
4	75	25	0	0	20/40/60	4	87 08 18
5	90	0	10	0	30/50/70	5	87 08 14
6	90	0	10	0	20/50/70	6	87 08 14
7	50	0	0	50	30/50/70	7	87 08 18
8	50	0	0	50	20/40/60	8	87 08 18

APPENDIX B

Measurements on Reinforcing Cages

Specimen: Z01

Cage No.	Nominal Cover (mm)	Reading No.	Stirrup to Form Distance (mm) left	center	right
1	30	1	32	31	30
		2	32	31	30
		3	31	31	30
2	50	1	50	51	49
		2	51	51	50
		3	52	51	50
3	70	1	70	72	69
		2	71	72	70
		3	71	72	70

Measurements on Reinforcing Cages

Specimen: Z02

Cage No.	Nominal Cover (mm)	Reading No.	Stirrup to Form Distance (mm) left	center	right
1	20	1	20	19	21
		2	20	19	20
		3	21	19	19
2	40	1	41	43	38
		2	40	40	41
		3	40	41	38
3	60	1	62	62	59
		2	62	62	60
		3	61	60	60

Measurements on Reinforcing Cages

Specimen: Z03

Cage No.	Nominal Cover (mm)	Reading No.	Stirrup to Form Distance (mm) left	center	right
1	30	1	30	32	30
		2	29	32	31
		3	27	31	30
2	50	1	48	49	50
		2	48	51	51
		3	50	52	50
3	70	1	71	73	70
		2	70	72	71
		3	71	71	72

Measurements on Reinforcing Cages

Specimen: Z04

Cage No.	Nominal Cover (mm)	Reading No.	Stirrup to Form Distance (mm) left	center	right
1	20	1	20	22	20
		2	20	21	19
		3	19	21	20
2	40	1	39	41	39
		2	39	41	40
		3	40	42	40
3	60	1	60	59	62
		2	60	60	60
		3	60	60	61

Measurements on Reinforcing Cages

Specimen: Z05

Cage No.	Nominal Cover (mm)	Reading No.	Stirrup to Form Distance (mm) left	center	right
1	30	1	29	32	30
		2	30	31	28
		3	29	31	30
2	50	1	49	49	50
		2	50	50	48
		3	50	52	49
3	70	1	70	71	70
		2	71	71	70
		3	72	72	69

Measurements on Reinforcing Cages

Specimen: Z06

Cage No.	Nominal Cover (mm)	Reading No.	Stirrup to Form Distance (mm) left	center	right
1	20	1	22	22	20
		2	20	21	20
		3	21	20	18
2	40	1	41	42	40
		2	40	42	41
		3	40	42	39
3	60	1	60	61	60
		2	60	61	60
		3	60	60	61

Measurements on Reinforcing Cages

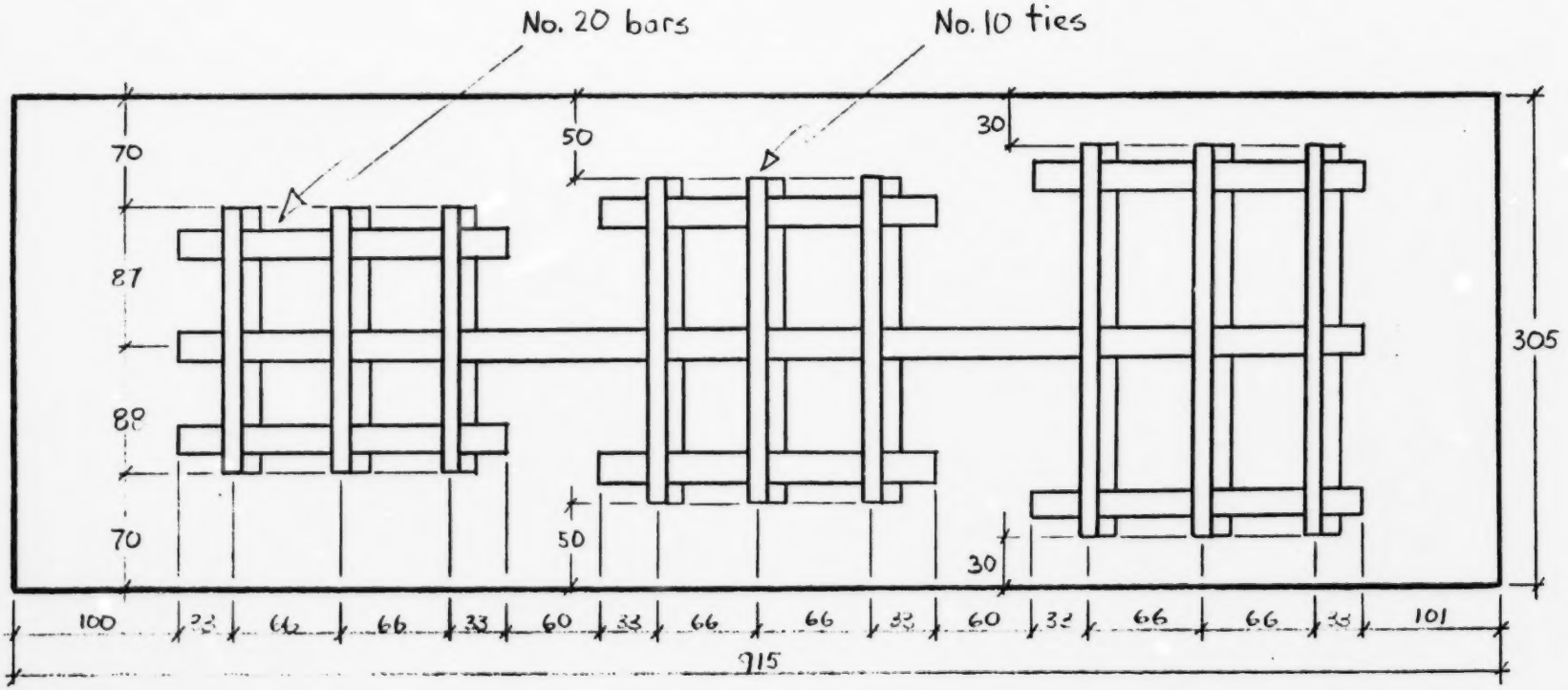
Specimen: Z07

Cage No.	Nominal Cover (mm)	Reading No.	Stirrup to Form Distance (mm) left	center	right
1	30	1	32	30	30
		2	31	31	27
		3	32	30	30
2	50	1	50	51	50
		2	51	52	50
		3	51	51	48
3	70	1	71	71	70
		2	71	70	71
		3	70	70	71

Measurements on Reinforcing Cages

Specimen: Z08

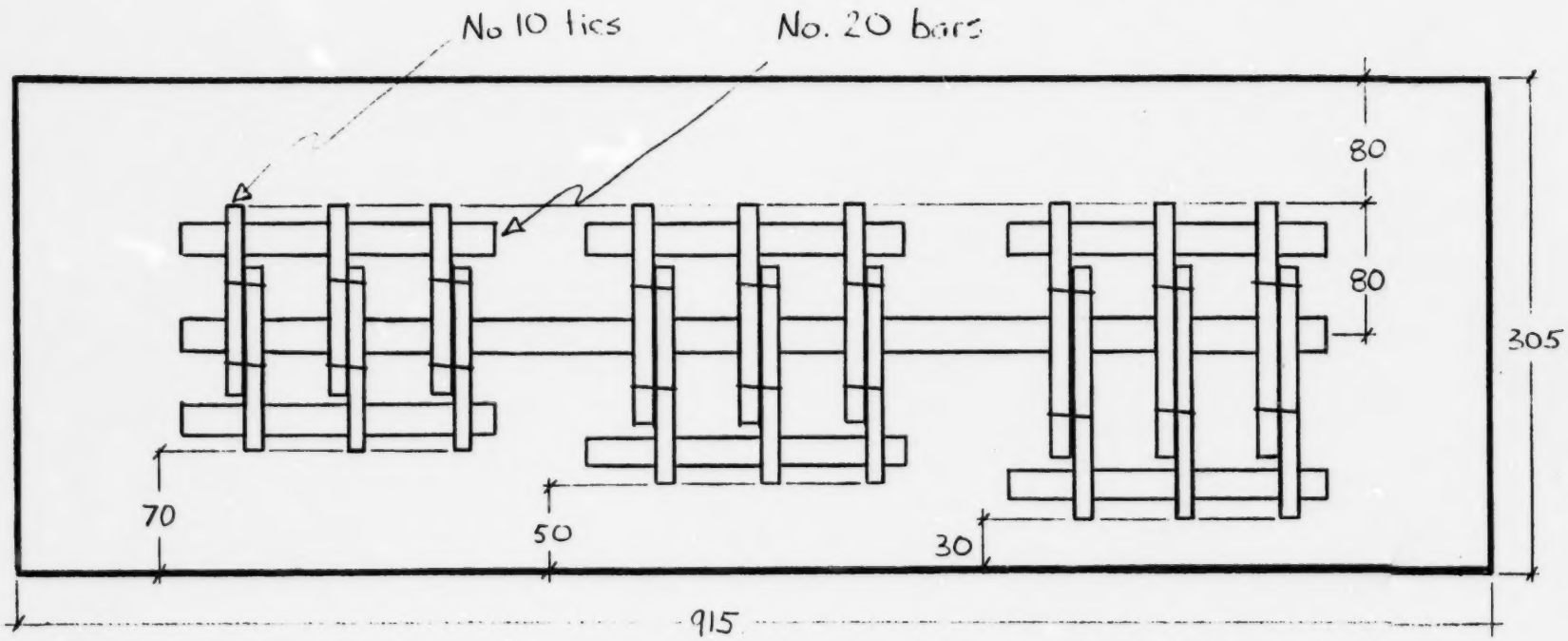
Cage No.	Nominal Cover (mm)	Reading No.	Stirrup to Form Distance (mm) left	center	right
1	20	1	20	22	19
		2	20	20	20
		3	19	20	20
2	40	1	39	40	39
		2	39	40	40
		3	40	40	40
3	60	1	61	61	61
		2	60	61	60
		3	61	61	61



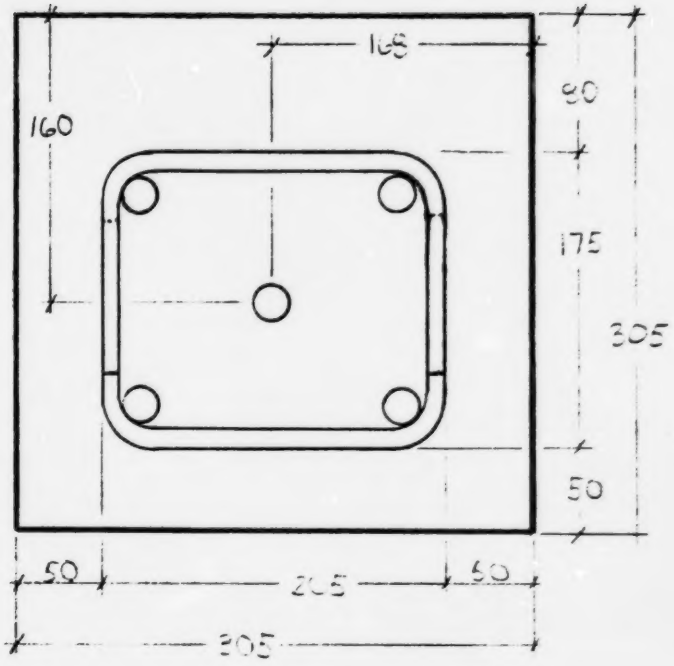
Plan View

Scale 1:4

1987 06 29



Elevation View
Scale 1:4
1987 06 29



Section View
Scale 1:4
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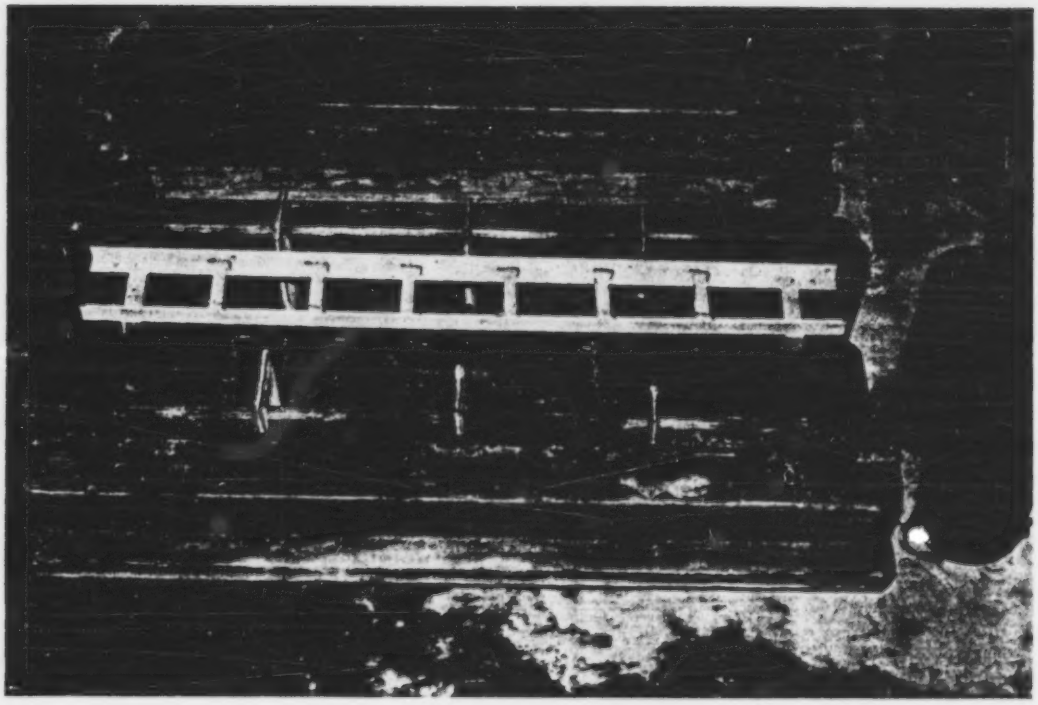

Photograph of reinforcing cages in position in mold

TABLES

TABLE I
Test Results on Materials Used

Physical properties and chemical analyses of cement, slag, fly ash and silica fume 1987

Description of tests	Portland Cement CSA Type 10	Slag	Silica Fume	Fly Ash
Physical tests - fineness				
Fineness- passing 75 μm, %	-	-	-	-
- passing 45 μm, %	84.5	-	95-100	-
- blaine, m^2/kg	390	-	-	-
Normal consistency, %	-	-	-	-
Setting time, min	106	-	-	-
Autoclave expansion, %	0.04	-	-	-
Physical tests - mortar strength				
Water content, %	-	-	-	-
Flow %	-	-	-	-
Compressive strength, MPa				
3-day	28.1	-	-	-
7-day	32.9	-	-	-
28-day	38.3	-	-	-
Pozzolanic activity with portland cement, %	-	-	-	-
Water requirement, % of control	-	-	-	-
Pozzolanic activity with lime,MPa	-	-	-	-
Chemical analyses				
SiO_2, %	20.42	37.34	94.0	43.14
CaO, %	62.65	37.20	-	0.46
CaO (free), %	0.66	-	0.3	-
Insoluble, %	0.91	-	-	-
LOI, %	2.25	-	2.8	-
Al_2O_3, %	5.95	9.07	0.3	23.45
Fe_2O_3, %	2.21	-	0.8	22.22
SO_3, %	3.79	-	0.6	0.85
MgO, %	1.46	12.71	0.4	0.90
Na_2O, %	-	-	0.20	0.51
K_2O, %	-	0.47	0.8	2.6
Alkalies (as Na_2O),	0.98	-	-	-
$CaSO_4$, %	-	-	-	-
C_3A, %	-	-	-	-

TABLE I (Cont'd)

Sieve Analysis of Fine Aggregate

Sieve Size	% Passing	CSA % Passing
5 mm	99.9	95 - 100
2.5 mm	86.7	80 - 100
1.25 mm	68.0	50 - 90
630 µm	46.2	25 - 65
315 µm	21.6	10 - 35
160 µm	8.0	2 - 10
PAN	1.6	0

Sieve Analysis of Coarse Aggregate

Sieve Size	% Passing #4 - 3/4	CSA % Passing
20 mm	100	90 - 100
14 mm	85.9	-
10 mm	54.4	25 - 60
5 mm	4.3	0 - 10
2.5 mm	2.1	0 - 5
1.25mm	2.0	-
PAN	0	-

TABLE II

Concrete Mix Descriptions

Series	Fly Ash (%)	Silica Fines (%)	Slag (%)	Cement (%)	Water Cementitious Ratio
Z01	0	0	0	100	0.5
2	0	0	0	100	0.5
3	25	0	0	75	0.5
4	25	0	0	75	0.5
5	0	10	0	90	0.5
6	0	10	0	90	0.5
7	0	6.4	50	50	0.5
8	0	6.4	50	50	0.5

TABLE III

Properties of Plastic Concrete

Mix	Date Cast	Air Content (%)	Unit Wt. (kg/m^3)	Slump (mm)	Concrete Temp. (°C)
Z01	85 07 12	6.0	2329	62	24
2	85 07 12	6.0	2336	72	25
3	85 07 12	6.6	2301	63	24
4	85 07 12	6.6	2251	67	24
5	85 07 12	6.1	2293	62	24
6	85 06 25	6.9	2265	63	25
7	85 06 25	7.0	2286	84	25
8	85 06 25	6.6	2301	87	25

TABLE IV

Unit Weight (kg/m^3)

Cylinder No.	Unit Wt.
Z01-1	2333
-2	2336
-3	2336
-4	2342
Z02-1	2331
-2	2348
-3	2338
-4	2330
Z03-1	2317
-2	2300
-3	2317
-4	2333
Z04-1	2313
-2	2305
-3	2309
-4	2312
Z05-1	2505
-2	2285
-3	2305
-4	2324
Z06-1	2287
-2	2274
-3	2276
-4	2289
Z07-1	2330
-2	2317
-3	2357
-4	2321
Z08-1	2345
-2	2342
-3	2347
-4	2333

TABLE V
Mix Proportions (kg/m^3)

Mix	Silica Fineo	FlyAsh	Cement	Slag	Water	F.A.	C.A.	A/E Agent ml/m^3	Mighty 150 ml/m^3
Z01	-	-	328.1	-	164.2	788.6	1048.0	152.2	-
2	-	-	338.6	-	169.6	780.5	1047.5	157.1	-
3	-	77.7	233.2	-	155.3	781.1	1053.2	307.4	-
4	-	76.0	228.1	-	152.1	764.1	1030.3	308.5	-
5	32.8	-	294.5	-	164.3	771.6	1029.9	270.3	886.9
6	32.4	-	290.8	-	162.5	761.9	1016.7	333.6	1251.1
7	-	-	159.3	159.3	159.1	757.9	1050.7	186.9	-
8	-	-	160.3	160.3	160.3	762.5	1057.1	184.2	-

TABLE VI
Compressive Strength

Cylinder No.	Strength in MPa	
	28 days	91 days
Z01-1	31.8	
-2	34.9	
-3		38.2
-4		38.1
Z02-1	30.5	
-2	35.5	
-3		39.7
-4		38.2
Z03-1	27.6	
-2	26.3	
-3		32.6
-4		33.3
Z04-1	25.7	
-2	26.0	
-3		33.0
-4		33.8
Z05-1	37.1	
-2	37.1	
-3		42.7
-4		45.6
Z06-1	39.3	
-2	37.1	
-3		39.0
-4		38.2
Z07-1	31.6	
-2	30.0	
-3		37.4
-4		34.0
Z08-1	30.2	
-2	31.6	
-3		36.7
-4		36.5

TABLE VII

Modulus of Elasticity at 28 Days

Cylinder No.	Modulus of Elasticity (MPa)
Z01-1	28970
-2	25320
Z02-1	24500
-2	27648
Z03-1	24040
-2	25400
Z04-1	26650
-2	24950
Z05-1	24491
-2	24835
Z06-1	27830
-2	25670
Z07-1	29540
-2	29130
Z08-1	30960
-2	28990